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THE IMPORTANCE OF AND PROGRESS IN THE UTILIZATION OF WIND POWER IN DENMARK

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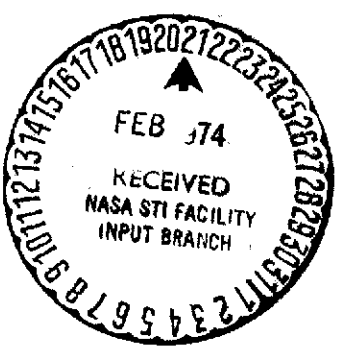

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The Importance of and Progress in the Utilization of Wind Power in Denmark

D. Stein.

The question of the utilization of wind power for /546 * electric power generation has gone beyond the theoretical investigations and discussions and has been brought closer to a practical solution in Germany too in the course of the last years through the participation of a series of notable agencies and construction companies. It is to be hoped that a large experimental wind power station within the framework of the German electric power supply can be delivered for practical operation in the near future. This power station would release a considerable number of remote consumers, who previously were dependent upon liquid or solid fuels, from the distribution net.

Experience obtained with wind power stations abroad is especially valuable for German projects. The electricity supply working committee has therefore investigated the status of wind power utilization in a series of countries in cooperation with the national labor association "wind power". The present work, which was prepared on the basis of an extensive on-the-spot study, treats the development of wind power stations in Denmark. Their number has increased strongly since the war started and is still increasing further[1]. After a short survey of the historical developments of wind power installations, we

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1. Also refer to W. Schieber, Wind Power Energy Source. Fackelträger Verlag, Berlin, 1942, pages 31 - 39.

*Numbers in the margin indicate pagination in the foreign text.

will cover the importance of the utilization of this energy source for the Danish power economy. These considerations are also of special interest for German conditions since they clearly outline the field of application for small wind power stations. In addition to details of construction in Danish installations, we will then especially interpret previous operational experience, which makes it possible to draw valuable conclusions about the amount of energy that can be generated in normal operation with a wind power station. The variations in power production will be followed up for the individual months of the year 1941 for 22 similar wind power stations. The daily energy generation was recorded for one installation for several months. Finally some efficiency calculations will be made.

The development of the wind power installations

Denmark was the first European country which turned its attention to the large unutilized amounts of energy in the wind and tackled the question of the practical utilization of these forces. The Danish government gave the well-known professor La Cour already in the year 1891 the task of building an experimental installation at Askov. He directed this installation until his death in the year 1908. During his 17 year long activity he especially looked into the idea of converting the mechanical energy of the wind into electrical current. In this way the main disadvantage of the windmills and wind engines, that the unregularly occurring wind energy could not be stored, was eliminated. La Cour designed a wind wheel with four vanes, which had a definite ratio of length to width. He let his generator work on a storage battery, which supplied the connected lines, and he himself developed the electric protective arrangements for this (the La Cours rocker). One can therefore consider the wind power installations he set up to be the first wind power stations. They were simple and very reliable in operation so they soon gained a wide distribution in Denmark. Here it is primarily the Lykkegaard Company in

Ferritslev on the Funen island that took advantage of La Cour's experience and started to build similar wind power installations.

The utilization of wind power in Denmark experienced its first great expansion during the First World War when the price of coal and diesel oil rose by leaps and bounds. (1 t bituminous coal cost 190 dkr in 1920, 15 dkr in 1931 and 30 dkr in 1939.) A large number of wind power installations were built as mechanical power sources and quite a series of wind power stations were built for electrical power supply in those years. Most of these installations were based on La Cours constructions. Towards the end of the war, when the great development in the aircraft industry also led to the use of the newly gained aerodynamic knowledge in the construction of wind power stations, Dr. Vinding created the Agricco wind power station (figure 1). Its vanes were built according to basic aerodynamic principles. This wind power station performed very well and was also built now and then after the war in Denmark and abroad. In connection with the development of the Agricco wind power station, Dr. Vinding with the late chief engineer R. Johs. Jensen attacked the task of generating alternating current with a wind power station. An asynchronous generator then had to be connected to the line when the speed of rotation exceeded the synchronous speed. Jensen worked on the construction of an alternating-current commutator machine, which had to follow the variations in the speed of rotation of the wind wheel. Unfortunately, nothing has been put down in writing about these investigations.

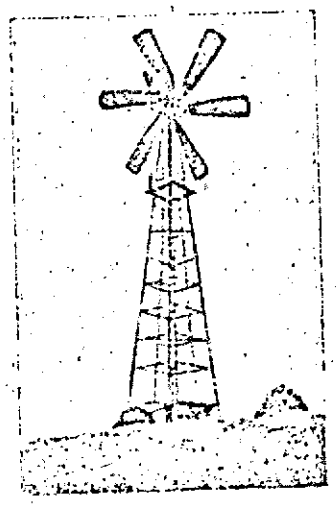

Fig. 1. Agricco Wind Power Station.

Professor Larsen suggested in connection with the above-mentioned work that the wind engine be connected with a direct-current generator and that the generated current would then drive a motor which again was to drive a synchronous generator. In this way it would be possible to drive the motor at a constant speed and eliminate the speed variations caused by the wind. The power produced by the generator would then be proportional to the magnitude of the torque of the motor. This idea has also occurred later on at various places. However, it must be kept in mind that as long as we are concerned with wind power station units of 30-50 kW (for 8 or 10 m/sec wind velocity) as is the case at present without exception, that kind of expense would be out of proportion to the obtainable benefits. Furthermore, for small wind power stations to be used for generating alternating current it would be practical to try to obtain an almost constant speed of rotation through speed regulation[2].

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[2]Compare with D. Stein: "Utilization of wind power in agriculture in the USSR." Elektrizitätswirtschaft, Vol. 40 (1941), pp. 54-56.

The second increase in the utilization of wind power in Denmark started with the outbreak of the war in 1939, when diesel oil and coal again became available only in limited amounts. The Lykkegaard company, which had delivered a whole series of wind power stations to Denmark and abroad - sometimes even to East Africa - in the years after the First World War, recognized the opportunity and built wind power stations with a nominal power of 30 - 35 kW for a whole series of smaller electric power companies. These small rural electric power stations had previously generated their power with diesel engines, but had to shut them down or switch over to generator gas. The newly-installed wind power stations work in parallel with the generator gas engines and in such a way that they took over the base load when the wind was strong enough. This resulted in a comparatively high utilization of the wind power stations.

When the Lykkegaard wind power stations were successfully being placed into operation, the idea of utilizing the wind power during the increasing shortage of fuel spread more and more. Thus the major company F. L. Smidth in Copenhagen on the request of their manager at that time, the present communications minister, engineer Gunnar Larsen, developed a wind power station designated "F.L.S.-Aeromotor" /347 designed according to modern concepts. This installation is calculated for a nominal load of 50 - 60 kW, and its wind wheel has a diameter of 17.5 m. In addition an even larger model has been built with a 24 m diameter blade and a nominal power of 70 kW. The F. L. Smidth company has already delivered more than 10 of this type of aeromotors, which are now being tested out in practice. Difficulties naturally occurred to start with so that the amount of energy produced was considerably smaller than had been assumed originally. The very inaccurate data on the wind velocities was a disadvantage in the design of the installation and in the efficiency

calculation. However, it seems that the necessary improvements have already partially been carried out since an F.L.S. Aeromotor with a 17.5 m wind wheel diameter installed near Copenhagen had achieved a power output level of 12,225 kWh in November 1941.

The significant development of wind power installations in the last two years can be recognized superficially from the number of wind power stations, although all these generator installations involve direct current stations. In July 1940 the number of wind power stations was 16, and by October 1941 the number rose to 64. The amount of power produced also increased along with the number of installations. In November 1941 64 wind power stations delivered 231,682 kWh. The total production can be estimated at approximately 1.8 million kWh for 1941 (figure 2).

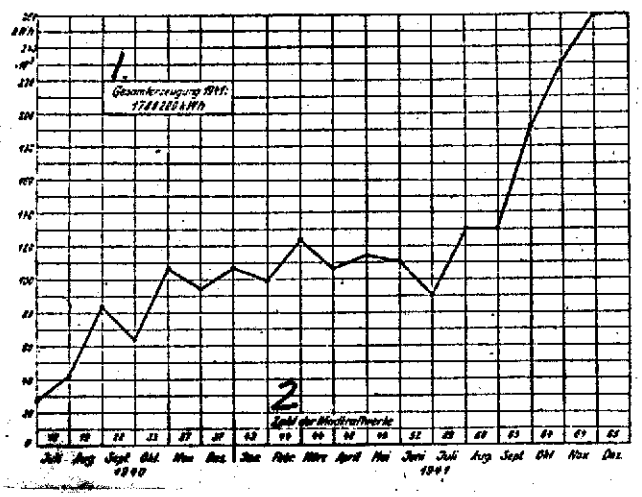

Figure 2. Production and number of Danish wind power stations (1940 - 1941).
Key: 1. Total production 1941: 1,780,200 kWh
2. Number of wind power stations.

A plan has recently turned up to build a large wind power station on one of the large islands which has a favorable location with respect to wind. Accurate wind measurements are already being carried out on one of the sites considered.

The importance of wind power utilization for the Danish power economy

The short survey of the development of wind power utilization in Denmark will lead to an investigation of its importance for the Danish power economy, and this will be followed by a discussion of technical and economic details. In order to be able to evaluate the progress and the prospects in wind power utilization correctly, the structure of the Danish electric power supply will first be discussed once in rough outlines from the technical and economic point of view as far as is necessary to understand the following explanations.

Structure of the Danish electric power system.

The Danish kingdom comprises a surface area of 44,335 km^2 with a population of approximately 3.7 million inhabitants in 1934. Since most of the population lives from agriculture, there are only a few larger cities besides the capital Copenhagen. The energy supply system is subdivided in accordance with this. There are large power stations only in Copenhagen. The smaller towns and the flat countryside are supplied from a large number of smaller and very small power stations, which are both of a municipal and cooperative nature. According to the latest available pre-war statistics for the year 1936 -37, the electric energy generation is distributed on a total of 487 public power stations. However, the overwhelming part, approximately 350 small direct-current power stations, are of only local importance. Their power production amounts to only approximately 25 million kWh yearly. Sixty-seven power stations remain with a production of less than 0.5 million kWh yearly. Besides there are also 13 power stations with a yearly production

of more than 5 million kWh each. The thirteen power stations delivered 75% of the total energy production of approximately 660 million kWh in the reporting year. Of this approximately 325 million kWh or approximately 50% was generated in Copenhagen.

The private electricity generation also plays an important role. The last count resulted in a number of 314 private electricity power stations with more than 30 kW power; they had a yearly production of 350 million kWh. In addition, there are 1,000 small generating installations which together produced only 4,000 kW. Additional electric power is also imported from Sweden and Germany.

Since Denmark has neither large waterfalls or coal deposits, the power stations have to resort almost exclusively to imported fuel. Coal accounts for the overwhelming part or 75% of the total electric power generated (1935/36). Diesel oil accounts for 20%, water power 4% and other energy sources 1%. In the year 1936-37 approximately 370,000 tons of coal (6.6% of all coal imported) and 52,000 tons of oil (20% of all oil imported) was used for electric power generation. The consumption of heating oil then varied between 0.3 and 0.35 kg/kWh, while the consumption of coal amounted to 0.75 kg/kWh in the large power stations and more than 2 kg/kWh in the smaller power stations. The larger stations operate largely with steam turbines, while the medium and small stations have to an important extent installed diesel engines. Table 1 gives the type of drives and the power of the engines for the year 1934.

Table 1. Type and power output for the engines in Denmark's public electric power stations (1934).

Type	Number of engines	Percent	Power 1000 kW	Percent
Steam power ...	60	5	270	65.0
Diesel engines .	892	75	131	32.0
Hydroelectric ..	116	10	10	2.3
Other types of drive	111	10	3	0.7
Total	1179	100	414	100.0

A widely branched intermediate voltage net, whose voltage is mainly 10 or 15 kW, is connected to the Danish high voltage distribution net. The low-voltage net delivers direct current to the supplied areas partly from transformer stations usually with a voltage of 380/220 V and partly from converter stations. The low voltage nets for alternating current supply are designed as star systems with a neutral line. The direct-current nets are mostly built as three-wire systems and in the rural areas also often as two-wire systems. 471 power stations contribute to the direct-current generation; of these, 428 produce only direct current and 39 produce both direct current as well as alternating current.

Although numerically there are far more direct-current power stations, the installed capacity of the alternating-current power station is considerably larger. Thus of the total engine capacity (1936-37), 79% was produced by alternating-current and only 21% was produced by direct-current generators. When one also considers that approximately 25% of the electricity generated with alternating current generators is converted into

direct current, one comes to the result that approximately 60% of the engine power serves for alternating-current and 40% for direct-current supply. However, in general the alternating-current generators have a considerably larger useful output for each kW of machine power. This also results from the location of the low-voltage lines. In the year 1936-37 there were approximately 42,000 low-voltage lines /348 for alternating current in Denmark (of which 39,000 km in rural areas) and 9,000 km of direct-current lines (of which 4700 km in the country). When evaluating these numbers one must, however, keep in mind that the distribution from every km of line is considerably smaller in rural areas than in the cities. These data still show that alternating current continues to play an important role in Denmark's energy supply.

The electric power supply in agriculture is of special importance because of the pronounced agricultural nature of the country. Individual towns and settlements here have often combined into cooperative electricity supply enterprises similar to selling and buying cooperatives. The Danish government has supported the formation of this type of cooperative electricity supply enterprises extensively, especially with monetary allocations.

In recent years one succeeded in increasing the current distribution considerably with extensive decreases in the rates so that the utilization of the power stations was accordingly improved considerably. Thus the yearly current consumption for a rural supply cooperative increased from 74 kWh (1928) to 450 kWh (1938) for each counter. Approximate recent current prices from before the war broke out are shown in table 2 where the average price for each kWh sold is compiled according to data from the year 1937. It must then be taken into consideration that the Danish electricity supply system before the war was completely dependent upon the importation of coal and oil, and that it was therefore sensitive

to price variations in the world market.

Table 2. Average price of each kWh sold in the year 1937[3].

	Light øre	Power øre	Heat øre	Additional fixed sales øre
Copenhagen	34.1	9.7	11.6	0.91
Other cities	36.0	10.6	9.25	1.70
Super power stations	26.6	13.5	8.32	13.2
Rural power stations	38.6	18.7	-	5.6

Besides these proper electricity supply cooperatives there is also a series of other types of enterprises. It must be emphasized that almost all cities have municipal power stations, which in part have also spread out over the neighboring agricultural areas.

Table 3 shows how the current from public electric power stations is distributed on cities and country. Although the production numbers shown already have been exceeded considerably, the sub-division into the individual current distribution areas is still of interest.

Table 3. Current distribution areas for the public electricity power stations in Denmark (1934-35).

		Light	Power	Heat
Total distribution ...	millions kWh	169	296	13
of which				
Copenhagen.....	%	42	40	0.5
Other cities.....	%	35	32	6.5
Rural	%	23	28	93

The government has a considerable influence on the energy supply. Since 11 May 1936 all new installations and expansions of electricity enterprises which serve the public power supply - thus also the wind power stations - come under the control of an electricity board. This council appointed by the government subjects all new reports to a thorough technical and economic testing, which especially takes into consideration whether the intended power supply situation can be solved in another technically more correct or economically more advantageous way. Furthermore, the electricity board is empowered to make decisions in case of disagreements between several power stations. The start of the war placed the electricity board in front of difficult tasks. The importation of coal and especially oil had to be limited considerably. One tried as much as possible to consolidate the smaller power stations or to connect them to the transmission lines in order to decrease the fuel consumption by extending the use over a greater period of time. The larger steam power stations - especially in Copenhagen - mixed considerable amounts of peat, which is available in Denmark in sufficient amounts, into the bituminous coal. This saved a considerable amount of coal. The small diesel installations started operating their engines with generator gas, which resulted in decreased performance and made the operation considerably more difficult and expensive.

Simultaneously with all these measures, the wind power was utilized more and more for energy generation. A series of wind power stations - mainly by the Lykkegaard company - existed already before the war, but their production was hardly important. Since several of the small rural electric power stations, that previously had worked with diesel engines, ordered wind power stations immediately at the beginning of the war, the number of these installations and thus their production increased considerably already in the year 1940. Every single new installation of wind power stations must first

be licensed by the electricity board according to the regulations in force. These authorities as well as the central agencies of the electricity supply many times held the opinion that the installation of wind power stations should only be considered as temporary measures, and that these installations therefore had to be subjected to a fast write-off. When this type of wind power station was approved, reference was accordingly also made to the fact that it would presumably be more advantageous to try to connect to a neighboring high-tension power station, since supply from the outside would mean a smaller expense for every kWh when based on a significant depreciation rate for the wind power installation.

These considerations are based on the assumption that the present war will be over comparatively fast and especially that the smaller rural electric power stations will soon have sufficient diesel oil available again at low prices. (A fast depreciation is naturally mandatory, since diesel engines then are less expensive than wind power stations in operation.) However, these expectations have not been met. It is not expected that Denmark will be able to count on unlimited importation of fuel already in the near future. On the other hand, the efforts to circumvent the difficulties by connecting to a high-voltage system are far from being successful all the time. It is still comparatively simple in smaller towns, which until now had their own diesel power stations of 500 - 2,000 kW in operation, since one here can count on an energy output which is still important. However, in a considerable number of villages and primarily on the small islands, which can be found in such large numbers, the high voltage lines are so far removed that economically it is hardly feasible to connect to them. One must also realize that the increased load on the very large power stations, which is caused by the increasing drain from the small electric power stations, results in additional consumption of coal, and that the larger power stations in part already have reached the

limit of their capacity. The question therefore arises whether it is justified to consider the wind power stations only as temporary auxiliary installations, that accordingly are subjected to a large depreciation rate.

In order to answer these questions, one must first investigate the technical suitability and the operational reliability of the wind power stations. The technical suitability can be especially confirmed for Denmark because - as has already been indicated - the largest part of the rural electric power stations works with direct current. On the other hand, the diesel engines in these installations have without exception been switched over to generator gas operation so that it is immediately possible to operate the diesel and the wind power installations in parallel. The wind power station then takes over the base load when the wind is strong enough. A storage battery is then charged up when the load is low. One must here keep in mind that every kWh generated by the wind power station represents a 100% fuel saving in contrast to operation with generator gas or when connected to the very large power station.

As far as the operational reliability is concerned, /349 several types of construction have here proved to be completely reliable as will be shown in more detail in the second part of the paper. On the basis of the experience obtained, one can assume a life duration of at least 12 - 15 years for wind power stations that are given appropriate maintenance. One can thus readily base the economic calculations on a depreciation time of 10 years. The specific costs for every kWh are naturally considerably smaller under these conditions than is often assumed in Denmark.

These considerations probably account for the decision in wide circles in favor of wind power stations, so that the strong upwards trend seems understandable. The course of this

development in terms of the number of wind power stations as well as the amount of energy generated is shown in figure 2. As can be seen, the amount of work obtained through utilization of wind power rose from July 1940 to almost four times as much in November 1940 and from then to nine and a half times as much in December 1941. However, in spite of this strong increase and in spite of the increasing number of wind power stations, one must realize that today approximately 75% of the total energy produced from large power stations is produced from coal, so that at the most 10 - 15 % of the present production is available for switching over to wind power. The question of whether medium and large wind power stations with capacities above 200 kW can be used has not been considered here, since neither the technical nor the economic basis for these installations has been clarified.

(Conclusion follows).

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16. Abstract

Denmark was one of the first countries to turn its attention to generating electric energy from wind power, because it has to import all oil and coal it uses, and it has virtually no hydroelectric power. A large number of wind power stations were built in the early years of World War I when fuel was scarce. The total production of wind power was estimated at approximately 1.8 million kWh in 1941. The installation of wind power stations was generally considered to be a temporary measure.

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